

A LARGE CARBON MONOXIDE CLOUD IN ORION

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ABSTRACT

Carbon monoxide line emission at $\lambda = 2.6$ mm has been observed over an area of $\sim 1\frac{1}{2}^\circ \times 4^\circ$ in L1630, a diffuse dark nebula bridging NGC 2024 and the reflection nebula NGC 2068. The absence of a 21-cm counterpart to this region of high visual extinction suggests that L1630 is mainly molecular hydrogen. The H_2 mass is estimated from the carbon monoxide observations to be $2.5 \times 10^4 \lesssim M \lesssim 1 \times 10^5 M_\odot$, a significant fraction of the total mass of stars and gas within the boundaries of the I Ori association.

Subject headings: molecules, interstellar — nebulae

Carbon monoxide is the most abundant interstellar molecule with a radiofrequency spectrum, and its 2.6 mm, $J = 1 \rightarrow 0$, line is the best available general-purpose tool for studying dense interstellar regions. In many parts of the Galaxy—in the vicinity of H II regions, along the Galactic plane, and in dark nebulae, for example—this line can apparently be detected almost at will (see, e.g., Penzias, Jefferts, and Wilson 1971; Penzias *et al.* 1972). This *Letter* describes observations of an extremely extended source of carbon monoxide in the diffuse dark nebula Lynds 1630, made with the 16-foot (5-m) telescope of the Millimeter Wave Observatory at Fort Davis, Texas.*

Lying within Barnard's Loop and hence the general confines of the I Ori association, L1630 stretches roughly from the Horsehead Nebula and NGC 2024 (Ori B) to the reflection nebulae NGC 2068 and 2071 nearly 4° to the northeast; according to Lynds (1962) its area is about 6 square degrees and its visual extinction about 4 mag. It contains numerous T Tauri (Herbig and Kuhi 1962) and late B to early A stars (Strom 1973), several small emission knots, and a Herbig-Haro object (Herbig and Kuhi 1962), and is presumably a region of intensive star formation. Judging from the stellar reddening there are several areas in L1630 where the extinction is much greater than 4 mag—probably reaching 10 mag or higher (Strom 1973).

At 2.6 mm the 16-foot antenna has a half-power beamwidth of $2\frac{1}{6}$. Calibration and correction for atmospheric absorption were done in the manner described by Davis and Vanden Bout (1973). The superheterodyne receiver used for the observations here had a double-sideband system noise temperature of about 1500° K. Spectral resolution of 0.65 km s^{-1} was provided by a bank of 40 filters, each 250 kHz wide. At this resolution a peak-to-peak noise fluctuation of 2° K (in brightness temperature) per channel could be reached in 15 min of observation.

Our carbon monoxide observations of L1630 were mostly of the common isotopic species CO at 115.27 GHz, but at 21 locations where this line was strong (mostly within 0.5° of the Horsehead) the isotopic ^{13}CO line at 110.20 GHz was also observed. The CO results are summarized in figure 1, and selected line profiles of both isotopic species are given in figure 2. The continuity of the CO emission strongly suggests an essentially localized cloud whose boundaries coincide at least approximately with those of the dark nebula. No overall rotation, such as Gordon (1970) claims for the

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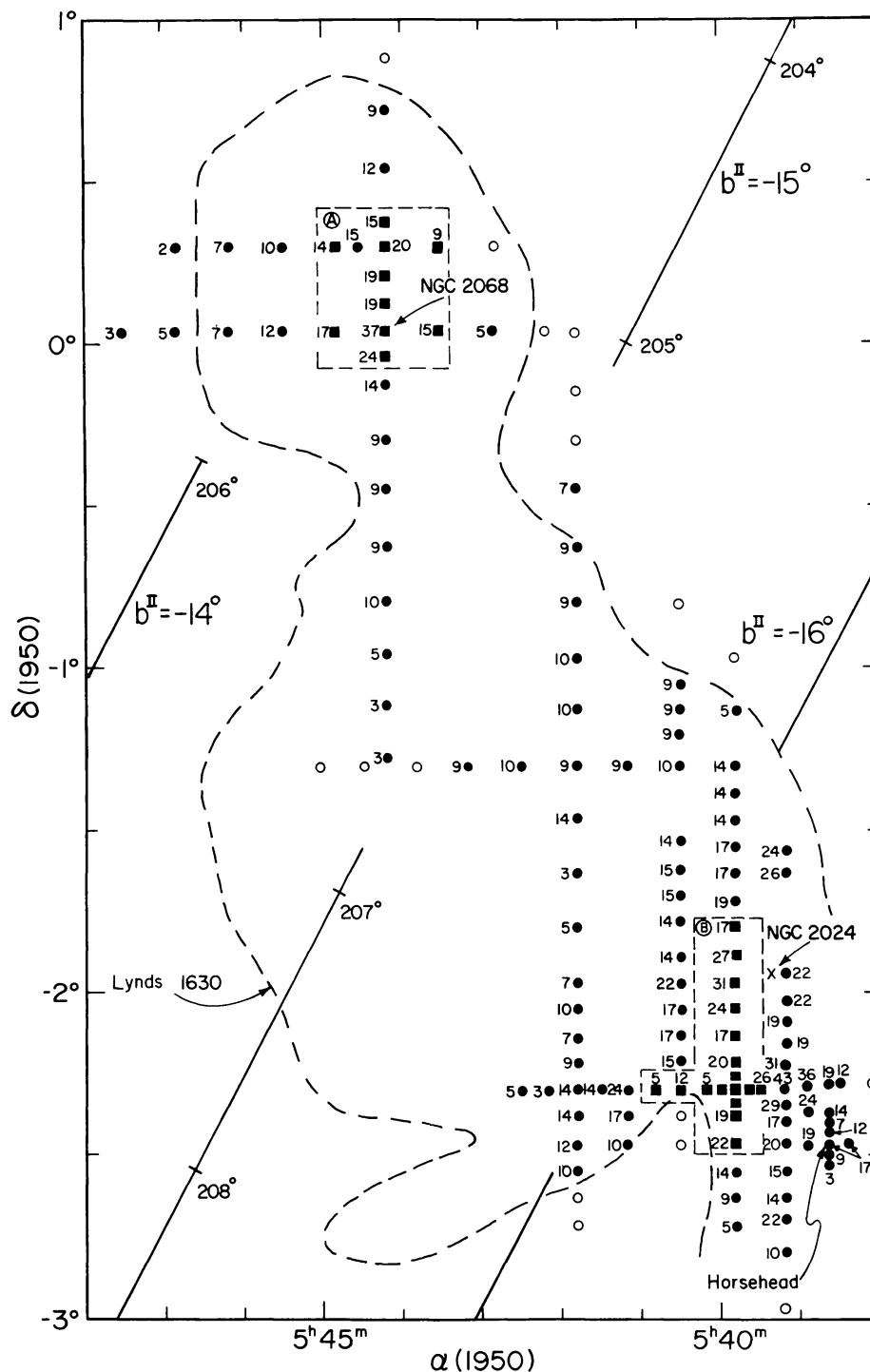


FIG. 1.—CO observations in L1630. Filled circles or squares are the size of the antenna beam and indicate locations where line emission was observed; the adjacent numbers give the peak line brightness temperature T_B corrected for atmospheric absorption. Open circles are negative results, $T_B \lesssim 2.5^\circ$ K. Integration times per point range from 5 to 30 min, and the entire map represents some 50 hours of observation. The dashed contour is a freehand sketch of the outline of the dark nebula on the Palomar *Sky Survey* blue print, and imperfectly conveys the very diffuse nature of this object.

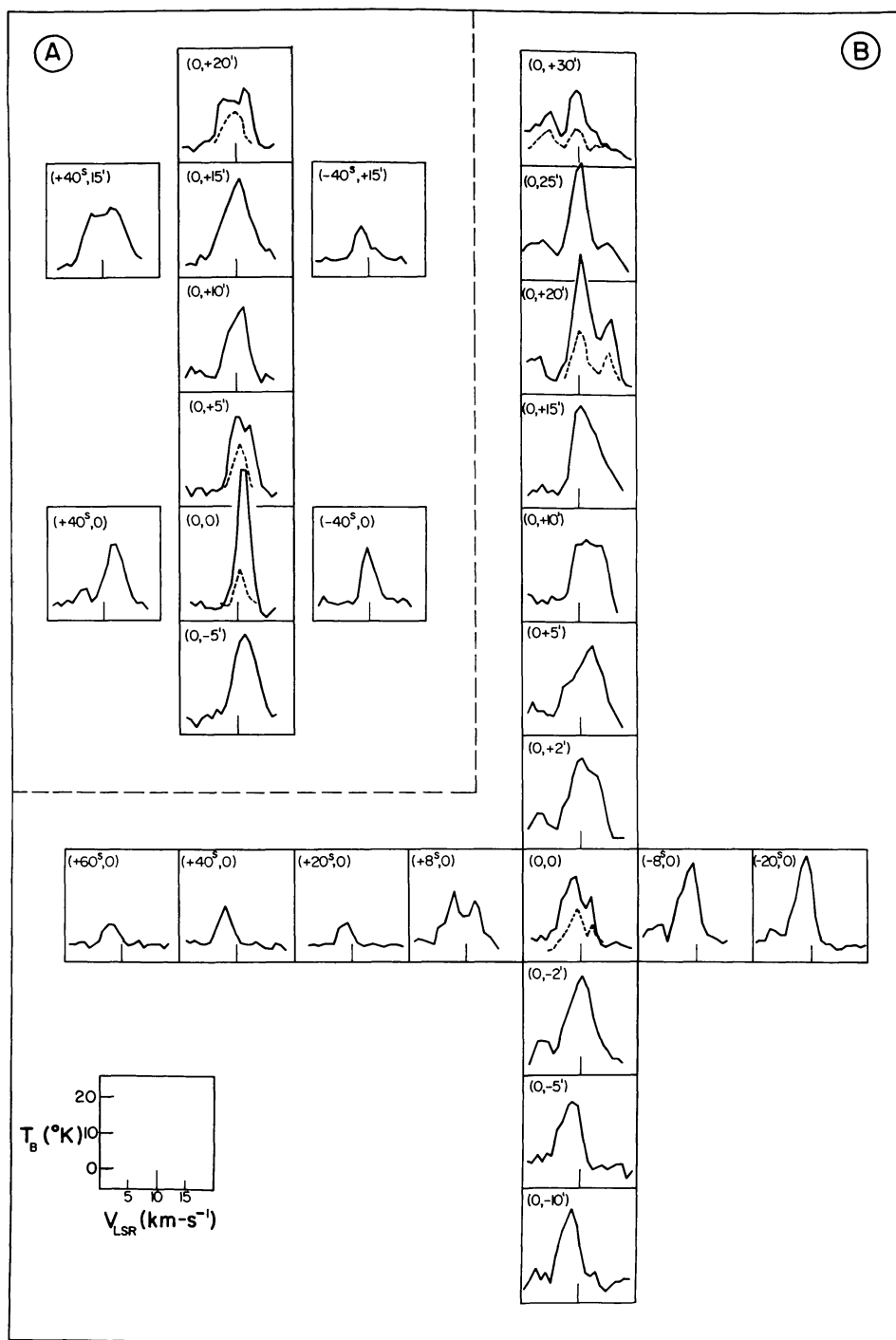


FIG. 2.—Selected line profiles of CO (solid lines) and ^{13}CO (dashed lines) in L1630, at locations indicated by filled squares in fig. 1. The brightness-temperature scale for ^{13}CO has been expanded by a factor of 3 in fig. 2B.

atomic hydrogen within the I Ori association, is evident; the mean velocity of lines in the general vicinity of NGC 2068 for example is within 1 km s^{-1} of the mean velocity of lines near the Horsehead and NGC 2024. For all CO profiles the mean LSR radial velocity is 9.6 km s^{-1} , and the rms radial velocity dispersion is 2.1 km s^{-1} ; the corresponding figures for ^{13}CO are 9.8 and 1.3 km s^{-1} .

It is clear from the figures that a good deal of CO intensity and velocity fine structure exists in L1630, which with further detailed mapping may turn out to be of great value in understanding the internal structure and dynamics of the nebula. Two phenomena in particular deserve mention: (i) an apparent tendency for the CO intensity to peak up on emission knots (NGC 2068 and $\alpha = 5^{\text{h}}39^{\text{m}}12^{\text{s}}$, $\delta = -2^{\circ}18'$ are locations where this occurs); and (ii) the occasional occurrence of double lines (in both isotopic species) at the fringe of emission regions. Further discussion of these and other details will be given elsewhere.

We turn now to the remarkably large overall mass of L1630 implied by the observations. Let us assume that L1630 is at 500 pc, the distance of the Orion Nebula, so its angular dimensions, $\sim 1\frac{1}{2}^{\circ} \times 4^{\circ}$, correspond to linear dimensions of $13 \times 35 \text{ pc}$; and let us further assume a thickness in the line of sight of at least 13 pc. Since L1630 is highly opaque and yet cannot be distinguished on the 21-cm surveys (e.g., van Woerden 1967; Gordon 1970; Heiles 1973), most of its hydrogen is probably molecular. A lower limit to the H_2 mass may then be obtained in two ways: either by taking 4 mag for the minimum visual extinction (Lynds 1962) and assuming a "normal" interstellar gas-to-dust ratio [$N(\text{H}_2)/E_v = 1 \times 10^{21} \text{ cm}^{-2} \text{ mag}^{-1}$], or by assuming a roughly uniform density, $n(\text{H}_2)$, and noting that $n(\text{H}_2) \gtrsim 300 \text{ cm}^{-3}$ (Green 1973) is required to produce perceptible 2.6-mm emission (otherwise the CO or ^{13}CO rotational levels simply equilibrate with the 3° K background radiation). These yield roughly the same result: $M \gtrsim 2.5 \times 10^4 M_{\odot}$. On the other hand, an upper limit on the mass may be obtained from the virial theorem to be $M \lesssim 5R\Delta v_r^2/G \approx 5 \times 10^4 M_{\odot}$, where $R \approx 11 \text{ pc}$ is the mean cloud radius, and Δv_r is the rms radial velocity dispersion of the H_2 , which we assume equal to that observed for CO, 2.1 km s^{-1} . A magnetic field in L1630 might raise this limit slightly: taking $H \lesssim 10^{-4}$ gauss as a reasonable limit (Turner and Verschuur 1970), one then finds from the virial theorem that $M \lesssim 1 \times 10^5 M_{\odot}$. We therefore estimate the total mass to lie in the range $2.5 \times 10^4 \lesssim M \lesssim 1 \times 10^5 M_{\odot}$.

(The observations incidentally confirm the idea that a good fraction of the available C and O in dense clouds exists in the form of CO [see, e.g., Herbst and Klemperer 1973]. On the assumption that the $^{13}\text{CO}/^{12}\text{CO}$ ratio is terrestrial, we estimate from the data that the mean CO column density in L1630 is at least $\sim 2 \times 10^{18} \text{ cm}^{-2}$, and therefore at least $\sim 20\%$ and possibly almost all of the total carbon probably exists in this form.)

By comparison, the total mass of the stars in the surrounding I Ori association is only $7 \times 10^3 M_{\odot}$ (Blaauw 1964), and the mass of the atomic and ionized hydrogen in which these are presumably embedded is estimated at 7×10^4 and $3 \times 10^4 M_{\odot}$, respectively (Menon 1958; Gordon 1970). L1630 therefore apparently represents a significant fraction of the total mass in the I Ori region, and would seem to be a plausible candidate for a new subassociation of I Ori in the process of formation. It is noteworthy, moreover, that a second dark nebula of comparable size and opacity, L1641, exists only some 5° to the south. We therefore conclude that as much as half or more of the total mass within the boundaries of the I Ori association may be in the form of molecular hydrogen, and has hitherto been largely overlooked.

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